Shunt Compensation for Power Quality Improvement using a STATCOM Controller

Parmar Hiren.S, Vamsi Krishna.K, Ranjit Roy
M.Tech Student, Associate Professor
Department of Electrical Engg S.V.N.I.T, Surat
hrn_drj1010@yahoo.com, vamsi.svnit@gmail.com, rr@eed.svnit.ac.in

***Abstract*— This paper addresses the issue of the modeling and analysis of STATCOM controller. The transient analysis and modeling is performed with the state-of-the-art digital simulator PSCAD 4.2.1. Simulation were carried out for both cases where, STATCOM was connected into the system and not, with simulation interval 3-5 sec. The aim of the STATCOM is to provide good power quality at the point of common coupling (PCC). Some simulation results are presented, which shows the compensation effectiveness of the STATCOM controller at the connected bus.**

***Keywords- Point of common coupling (PCC), Power Quality, PSCAD, STATCOM, VSC*.**

I. INTRODUCTION

In recent years power quality issues have become more and more important both in practice and in research. Power quality can be considered to be the proper characteristics of supply voltage and also a reliable and effective process for delivering electrical energy to consumers. Binding standards and regulations impose on suppliers and consumers the obligation to keep required power quality parameters at the point of common coupling (PCC). Interest in power quality issues results not only from the legal regulations but also from growing consumer demands. Owing to increased sensitivity of applied receivers and process controls, many customers may experience severe technical and economical consequences of poor power quality. Disturbances such as voltage fluctuations, flicker, harmonics or imbalance can prevent appliances from operating properly and make some industrial processes shut down. On the other hand, such phenomena now appear more frequently in the power system because of systematic growth in the number and power of nonlinear and frequently time-variable loads.

When good power quality is necessary for technical and economical reasons, some kind of disturbance compensation is needed and that is why applications of power quality equipment have been increasing.

The most recent approach for solid-state power compensators is based on self-commutated converters using components with a current blocking capability. Such a compensation system is the static equivalent of the synchronous compensator, hence the term STATCOM [1] (static synchronous compensator).A STATCOM can provide fast capacitive and inductive compensation and is able to control its output current independently of the AC system voltage (in contrast to the SVC, which can supply only diminishing output current with decreasing system voltage). This feature of the compensator makes it highly effective in improving the transient stability. Therefore, STATCOM systems with GTO thyristors have been initially used for improving flexibility and reliability of energy transmission in FACTS (flexible AC transmission system) applications [2]-[3].As the switching frequency of GTOs must be kept low, the control with fundamental frequency switching has been used and multi-phase configurations have been formed to reduce harmonics production. The newest applications of STATCOMs concern power quality improvement at distribution network level. Some examples given in the literature are the reduction of flicker, voltage control and balancing single phase load [4]-[5]. These are systems of a smaller power where IGBT or IGCT technology can be applied allowing fast switching with PWM control.

Although the possibility of using STATCOMs for the reduction of influence of disturbing loads on the supply network has already been proved in practice, there is still a lack of information about the complex assessment of compensation effectiveness and a method of system selection and its control for a given network.

II. BASIC CONFIGURATION OF STATCOM

The STATCOM is a shunt device. It should therefore be able to regulate the voltage of a bus to which it is connected. The operating principle of a STATCOM in this mode has been termed as the STATCOM in voltage control mode. This paper shows that even though the structure of STATCOM used in both current control and voltage control modes is the same, its operating principle is different. In the current control mode it is required to follow a set of reference currents while in the voltage control mode it is required to follow a set of reference voltages. This paper discusses the reference voltage generation scheme and the control of STATCOM in the voltage control mode. In its most basic form, the STATCOM configuration consists of a VSC, a dc energy storage device; a coupling transformer connected in shunt with the ac system, and associated control circuits. Fig.1 shows the basic configuration of STATCOM. The VSC converts the dc voltage

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across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allows effective control of active and reactive power exchanges have been made to remed the situation with solutions based between the STATCOM and the ac system. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power.
- Correction of power factor.
- Elimination of current harmonics.

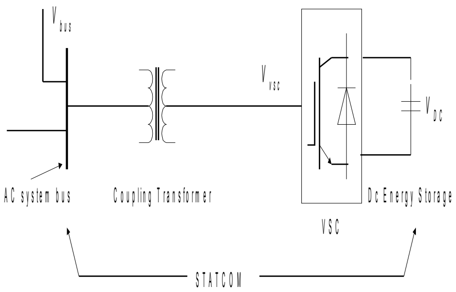


Fig.1 Basic configuration of STATCOM.

III. Principle of STATCOM

Statcom is to suppress voltage variation and control reactive power in phase with system voltage. It can compensate for inductive and capacitive currents linearly and continuosly. Fig.2 shows the vector diagram at the fundamental frequency for capacitive and inductive modes and for the transition states from capacitive to inductive and vice versa.The terminal voltage (V_{bus}) is equal to the sum of the inverter voltage (V_{vsc}) and the voltage across the coupling transformer reactive V_L in both capacitive and inductive modes. It means that if output voltage of STATCOM (V_{vsc}) is in phase with bus terminal voltage (V_{bus}) and V_{vsc} is greater than V_{bus}, STATCOM provides reactive power to system. If V_{vsc} is smaller than V_{bus}, STATCOM absorbs reactive power from power system. V_{bus} and V_{vsc} have the same phase, but actually they have a little phase difference to component the loss of transformer winding and inverter switching, so absorbs some real power from system.

Fig.2 is Statcom vector diagrams, which show inverter output voltage $V_{I,}$ system voltage $V_{T,}$ reactive voltage V_L and line current I in correlation with magnitude and phase δ. Fig.2. a and b explain how V_I and V_T produce capacitive or inductive power by controlling the magnitude for inverter output voltage V_I in phase with each other. Fig 2.c and d show STATCOM produces or absorbs real power with V_I and V_T having phase±δ. The transition from inductive to capacitive mode occurs by charging angle δ from zero to a negative value. The active power is transferred from the AC terminal to the DC capacitor and causes the DC link voltage to rise. The active and reactive power may be expressed by the following equations:

$$P = (V_{bus}V_{vsc}/X_L)\sin \delta$$

$$Q = (V^2_{bus}/X_L) - (V_{bus}V_{vsc}/X_L)\cos \delta$$

V_{vsc} – out put voltage of STATCOM

V_{bus} – bus terminal voltage

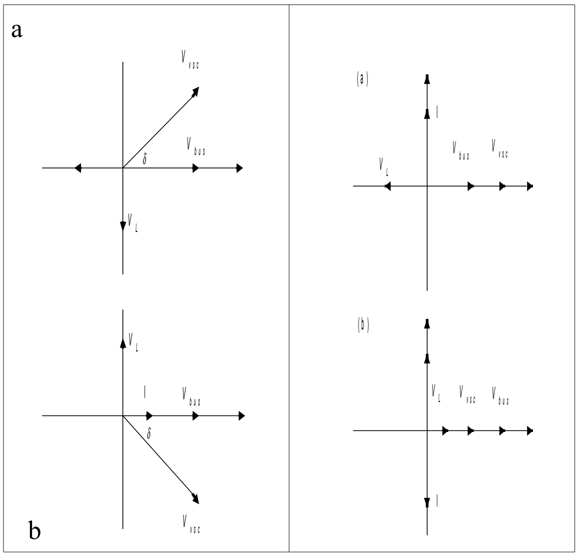
X_L - inductive reactance of coupling transformer

IV Modeling and Control Description

A typical ac system equivalent was used in this study to show the dynamic performance of the STATCOM. The simulated circuitry representing this integration is shown in Fig 3. The detailed representation of the STATCOM is depicted in Fig 4. In the figures, the units of resistance, inductance, and capacitance values are Ohms, Henry, and microfarad, respectively.

V The AC Power System

The ac system equivalent used in this study corresponds to a two-machine system, where one machine is dynamically modeled (including generator, exciter, and governor) to be able to demonstrate dynamic oscillations. Dynamic oscillations are simulated by creating a three-phase fault in the middle of one of the parallel lines at BusD (Fig.1).A bus that connects the STATCOM to the ac power system is named a STATCOM terminal bus. The location of this bus is selected to be either



bus A or B.

Fig.2 Vector diagram of STATCOM (a) capacitive mode, (b) inductive mode, (c) active power release and (d) active power absorption.

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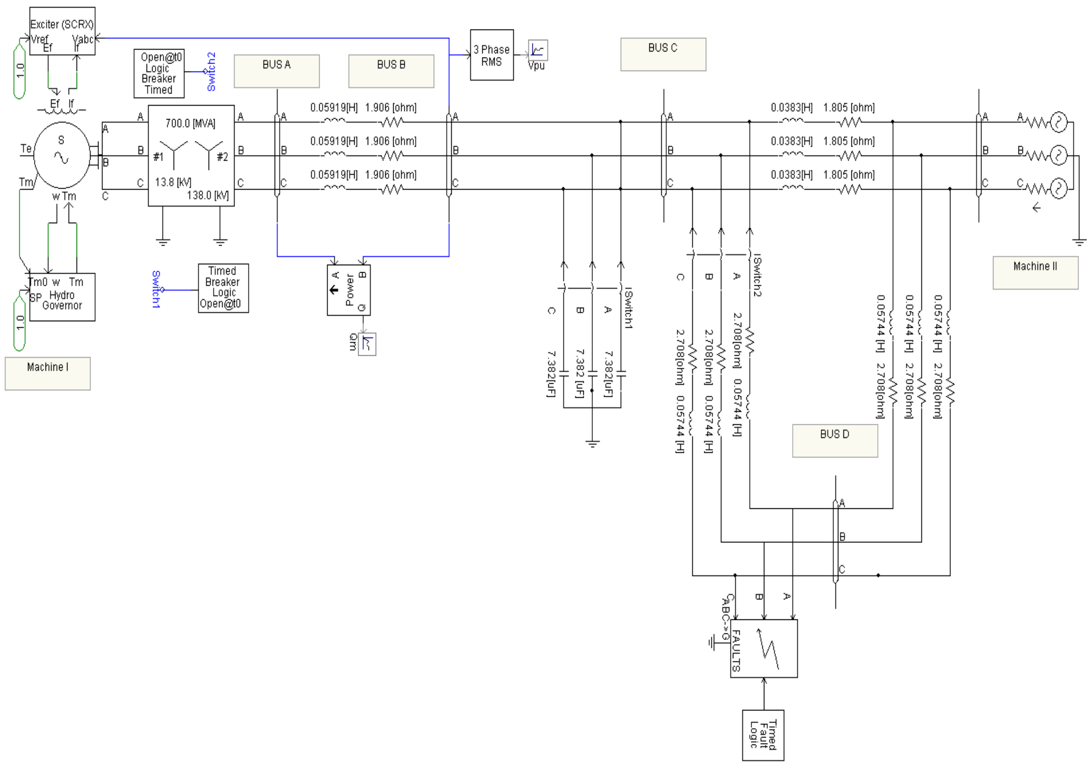

Fig.3 AC system equivalent.

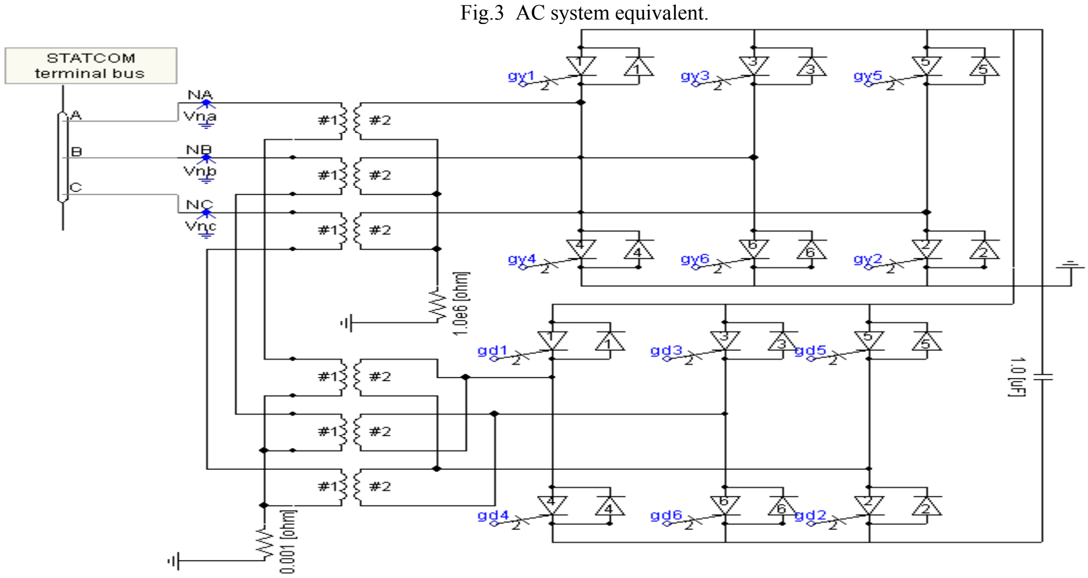

Fig. 4 Detailed repersentation of the STATCOM.

V. STATCOM SIMULATION

It is seen from Fig.4 two gate turn-offs (GTO) based six-pulse voltage source inverters represent the STATCOM used in this particular study. The voltage source inverters are connected to the ac system through two coupling transformers and linked to a dc capacitor in the dc side. The value of the dc link capacitor has been selected as 1 μF in order to obtain smooth voltage at the STATCOM terminal bus.

The most basic is a six-pulse system configuration, giving the rectangular output voltage. As such a system produced harmonics and its practical application is limited. A multi-pulse scheme is one of the solutions used for harmonic reduction, in which several identical six-pulse bridges are connected to transformers having outputs that are phase displaced with respect to one another. Star- and delta-connected winding give a relative 30° phase shift and, with two six-pulse converter bridges connected, allows 12-pulse STATCOM operation to be obtained.

As stated in [6]-[7], a GTO-based inverter connected to a transmission line acts as an

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alternating voltage source in phase with the line voltage, and, depending on the voltage produced by the inverter, an operation of inductive or capacitive mode can be achieved. It has also been emphasized that a dc link capacitor establishes equilibrium between the instantaneous output and input power of the inverter. The primary function of the STATCOM is to control reactive power/voltage at the point of connection to the ac system [6]-[8]. Fig.5 shows the control diagram of the STATCOM used in the simulation.

STATCOM control system exerts reactive angle control as follows: an error signal is obtained by comparing the reference reactive power Q_{ref} with the reactive power measured Q_m at the load point. The PI Controller process the error signal and generates the required angle (alpha_ord) to drive the error zero.

PLL (3-phase PI controlled phase locked loop), which generates a ramp signal theta that varies between 0 and 360°, synchronized or locked in phase, to the input voltage Va.

Interpolated Firing Pulses**:** The output is based on a comparison of high (H) and low (L) input signals. The low L input is normally a firing angle order (order) and the high H input is from a phase-locked oscillator or equivalent.

Two signals are being sent to each switch, the first one tells to turn on or off, the second one, determines an exact moment of switching and is used by interpolation procedure which allows for switching between time steps.

To generate the gating signals for the inverters, line to ground voltages are used for the inverter connected to the Y-Y transformer, whereas line-to-line voltages are utilized for the inverter connected to the Y-Δ transformer.

VI Case Studies

In order to demonstrate the effectiveness of the STATCOM case are simulated. A three- phase fault is created at Bus D of Fig.1. to generate dynamic oscillations in each case. The plot time step is 0.001 s for all the figures given in these cases.

VII AC Oscillations and STATCOM- Mode

A two-machine ac system is simulated. The inertia of machine I was adjusted to obtain approximately 3-Hz oscillations from a three-phase fault created at 3.1 s and cleared at 3.25 s. When there is no STATCOM connected in the ac power system, the system response is depicted in the Fig.6. in the interval of 3-5 s where ac voltage is at Bus B. The response with STATCOM is connected shown in Fig. 7.

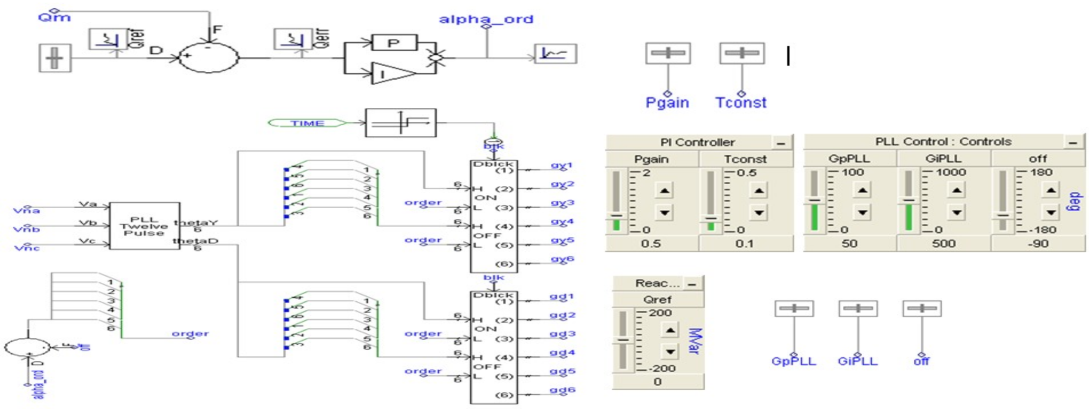

Fig. 5 STATCOM controls.

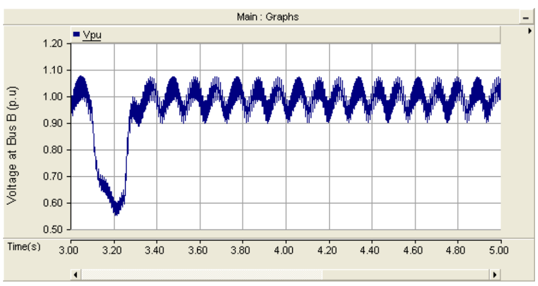

Fig.6. AC voltage at BUS B when a STATCOM is not connected

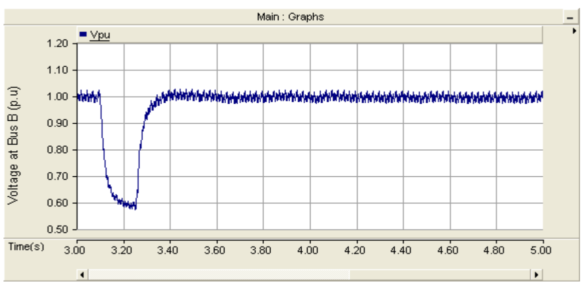

Fig.7 When a STATCOM is connected at BUS B

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VIII. Conclusions

This paper presents the modeling and control of the STATCOM and its dynamics response to system oscillations cause by a three-phase fault. It has been shown that the STATCOM can be very effective in damping power system oscillations.

The use of computer programs in the simulation of STATCOM, including their controls, is extremely important for the development and understanding of this power electronics based technology. The results achieved through the digital simulations clearly show the capability of the STATCOM to provide good power quality at the point of common coupling (PCC).

It was also observed that the location where the STATCOM is connected important for improvement of overall system dynamics performance. STATCOM compensator will become a good solution for power quality improvement.

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